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SOURCES AND AVAILABLE SUPPLIES OF COMMERCIAL FERTILIZERS

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INTRODUCTION

Maintaining the fertility of the soil by means of fertilizers is one of the important agricultural problems. The use of crop and animal wastes and other substances containing organic materials to fertilize land dates back at least to 1000 B. C., while chemical fertilizers as such have been used less than a century. The present chemical fertilizer practices may be said to have had their inception in 1840, when Liebig in Germany showed how the productivity of the soil could be increased by the application of the proper chemical compounds. A practical process for treating phosphate rock with sulfuric acid to produce available phosphoric acid in a material now known as superphosphate was, no doubt, the first step in the development of the chemical fertilizer industry. This process was established and patented by Lawes in England in 1842. By the time of the Civil War, in addition to manure, leafmold, marl, fish, ground bone, and wood ashes, which had been used by the early colonists in this country, cottonseed, a small amount of sulfate of ammonia, nitrate of soda,

[1] The writer wishes to acknowledge the assistance given by the staff of the Fertilizer Research Division, especially A. L. Mehring, K. G. Clark, and Albert R. Merz.

Peruvian guano, superphosphate, and spent bone black were used. Table 1 indicates the present magnitude and value of the fertilizer industry in the United States.

TABLE 1.—*Materials consumed as, or used in the manufacture of, fertilizer in the United States* [1] *in 1937 and their value at place of production or ports*

Item	Quantity	Wholesale price per ton	Total value
	Tons	*Dollars*	*Dollars*
Phosphate rock	1,800,000	3.00	5,400,000
Sulfuric acid (50° Baumé)	2,000,000	10.00	20,000,000
Bonemeal and other phosphates	190,000	23.00	4,370,000
Muriate of potash	550,000	28.00	15,400,000
Sulfate of potash	76,000	36.00	2,736,000
Manure salts and kainit	160,000	13.00	2,080,000
Other potash materials	120,000	22.00	2,640,000
Sodium nitrate	800,000	26.00	20,800,000
Ammonium sulfate	760,000	27.00	20,520,000
Anhydrous ammonia and ammonia liquors	100,000	50.00	5,000,000
Other chemical nitrogenous materials	310,000	30.00	9,300,000
Organic ammoniates	690,000	33.00	22,770,000
Fillers, limestone, dolomite, etc	1,050,000	1.00	1,050,000
Total	8,606,000	15.35	132,066,000

[1] Including Hawaii and Puerto Rico.

The results of discoveries and of chemical research are largely responsible for the decline in the prices of fertilizers, which are now less than half of what they were in 1880, when systematic records in the fertilizer trade were first kept in this country.

In 1937, although it had only one-sixteenth of the population of the world, the United States used one-fifth of the world production of 44,000,000 tons [2] of manufactured fertilizer. Table 2, compiled from data published in The Fertilizer Review, shows the consumption of fertilizer in the United States from 1910 to 1939.

In recent years more than 30 kinds of material have been used in making commercial fertilizers in the United States. The greater part, both in tonnage and value, of agricultural chemicals, that is, chemically processed materials used on the farm, go into fertilizers. In 1937 raw materials valued at $132,066,000 were processed. The processed materials, which had a wholesale value of $170,000,000, were sold to the farmer for $220,000,000.

The expenditure for fertilizer by the farmer during the past 25 years ranged from 1.80 to 2.86 percent of the gross farm income. It was 2.52 percent in 1938. It is exceeded in the cost of crop production by only 5 other items—farm equipment, labor, feed, interest, and taxes. On the average, the farmer pays $200,000,000 for 7,000,000 tons of fertilizers annually.

The commercial fertilizer used in the United States each year contains an average of 278,000 tons of nitrogen (N), 665,000 tons of phosphoric acid (P_2O_5), and 276,000 tons of potash (K_2O), or a total of 1,219,000 tons of plant food, with a ratio of approximately 1:2:1. The amounts are given in terms of N, P_2O_5, and K_2O because this is now the established usage in listing plant-food materials. If listed in terms of N, P, and K, the amounts would be 278,000 tons of nitrogen, 290,000 tons of phosphorus, and 229,000 tons of potassium, or a ratio of 1.00:1.04:0.824. This is probably a better method of comparison than the $N:P_2O_5:K_2O$ ratio.

[2] Short tons (2,000 pounds) is the unit used here and throughout the publication.

TABLE 2.—*Consumption of fertilizer in the United States from 1910 to 1939* [1]

[Based on tag sales, records of State officials, or estimates]

State	1910–14 average	1915–19 average	1920–24 average	1925–29 average	1930–34 average	1935	1936	1937	1938	1939 (estimated)
	Tons	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
New England	251,490	294,634	343,954	353,125	326,820	280,511	290,299	335,768	309,942	301,000
Maine	113,760	118,968	168,275	176,030	173,930	125,000	130,000	140,000	140,000	138,000
New Hampshire	15,050	15,766	15,800	15,191	11,800	16,000	16,500	18,000	16,500	16,000
Vermont	13,040	15,400	17,200	17,203	13,568	15,295	16,421	25,260	20,067	19,000
Massachusetts	48,140	60,400	62,819	66,476	62,121	63,208	64,481	74,272	69,175	67,000
Rhode Island	7,300	8,900	8,860	9,047	8,201	10,000	10,000	11,000	12,200	11,000
Connecticut	54,200	75,200	71,000	69,178	57,200	51,008	52,897	67,236	52,000	50,000
Middle Atlantic	962,068	1,006,796	963,995	995,083	873,944	936,988	1,052,888	1,192,865	1,137,385	1,073,000
New York	257,580	284,972	246,000	258,992	238,600	235,000	315,000	350,000	332,881	315,000
New Jersey	142,415	152,408	163,011	145,880	139,482	149,408	160,741	183,952	171,596	165,000
Pennsylvania	331,123	319,996	320,969	334,395	273,541	294,937	318,330	370,162	375,000	350,000
Delaware	36,600	44,880	42,541	41,754	35,192	37,800	39,000	44,466	38,000	34,000
Maryland	163,670	172,280	155,006	169,491	145,471	164,843	164,817	186,285	166,408	158,000
West Virginia	30,680	32,260	36,468	44,571	41,658	55,000	55,000	58,000	53,500	51,000
Southern	4,348,954	3,866,369	4,022,076	5,116,978	3,781,584	3,961,288	4,310,612	5,312,094	4,786,328	4,884,394
Virginia	385,353	424,769	429,785	432,496	350,391	378,536	386,474	440,430	405,179	418,982
North Carolina	750,252	806,023	1,012,353	1,250,086	941,559	1,000,071	1,038,920	1,236,564	1,104,788	1,207,654
South Carolina	984,826	890,759	752,361	797,696	589,583	613,561	626,446	771,198	660,963	672,753
Georgia	1,146,284	884,832	683,013	804,868	587,541	617,439	684,522	866,360	768,323	736,179
Florida	199,709	216,737	334,066	414,103	412,904	418,239	512,577	579,399	555,475	547,698
Alabama	476,829	261,249	346,444	609,686	383,100	422,400	467,700	629,260	528,850	552,600
Mississippi	131,235	90,500	149,871	283,202	190,378	214,015	239,027	325,320	325,836	293,478
Tennessee	75,739	98,094	94,731	140,891	103,061	96,444	117,305	141,325	128,291	133,911
Arkansas	51,370	60,665	62,451	121,604	60,170	39,630	48,931	68,675	67,800	70,822
Louisiana	88,880	89,372	90,278	127,194	91,427	92,532	117,106	157,318	148,542	150,046
Texas	56,977	40,369	63,503	128,691	66,750	61,802	65,549	89,400	84,276	92,738
Oklahoma	1,500	3,000	3,220	6,461	4,720	6,619	6,055	6,845	8,005	7,533
Middle West	524,828	679,067	780,551	912,936	697,675	821,556	982,970	1,049,342	986,408	1,006,915
Ohio	165,652	220,650	298,058	319,735	243,673	306,509	337,146	362,205	324,288	305,000
Indiana	177,654	185,930	204,004	233,242	143,462	194,944	245,537	226,887	220,967	265,053
Illinois	6,200	9,800	14,991	28,875	25,097	23,827	31,308	36,076	36,132	42,648
Kentucky	69,200	94,200	82,400	87,700	79,039	73,502	89,392	117,078	109,968	111,201

[1] Does not include the concentrated superphosphate distributed by AAA, rock phosphate sales in Illinois, or fertilizer sold in the District of Columbia, Hawaii, or Puerto Rico.

TABLE 2.—*Consumption of fertilizer in the United States from 1910 to 1939*—Continued

[Based on tag sales, records of State officials, or estimates]

State	1910–14 average	1915–19 average	1920–24 average	1925–29 average	1930–34 average	1935	1936	1937	1938	1939 (estimated)
Middle West—Continued.	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*	*Tons*
Missouri	47,326	68,800	58,596	60,149	43,972	59,398	93,588	82,498	70,301	66,421
Michigan	48,786	78,300	92,116	126,919	100,603	111,288	125,693	144,500	132,702	125,000
Wisconsin	3,300	6,400	13,800	24,946	31,865	28,414	32,184	42,872	46,433	47,000
Minnesota	1,800	3,600	6,000	12,343	11,606	10,776	9,899	12,386	13,778	14,500
Iowa		1,100	3,700	10,076	13,319	5,000	6,403	8,523	11,146	11,500
Kansas	4,910	10,107	6,111	7,758	3,823	7,208	11,170	15,267	18,099	15,992
Nebraska		140	470	566	400	200	200	500	1,794	1,800
South Dakota		20	145	171	120	100	100	150	150	150
North Dakota		20	160	456	696	300	350	400	650	650
Western	48,514	45,678	84,787	136,027	169,594	217,788	263,581	304,630	284,001	288,650
Montana				98	450	300	3,770	4,000	5,000	5,000
Wyoming				222	460	1,308	1,300	1,400	1,500	1,500
Idaho		60	340	772	1,220	3,000	3,000	4,417	9,015	9,000
Colorado		60	230	619	1,715	1,200	1,500	1,800	4,393	4,400
Utah		60	300	453	1,760	750	2,000	3,000	5,000	5,000
Nevada			28	43	148	500	500	500	500	500
Arizona		300	425	1,281	1,980	3,393	4,000	10,500	6,500	6,500
New Mexico	20	400	780	1,552	1,065	1,636	2,667	3,218	2,240	2,250
California	43,234	35,998	70,384	106,792	134,796	178,701	207,244	232,795	208,353	213,000
Oregon	3,960	6,700	6,900	9,493	10,400	10,500	14,300	15,000	14,500	14,500
Washington	1,300	2,100	5,400	14,702	15,600	16,500	23,300	28,000	27,000	27,000
United States	6,135,854	5,892,544	6,195,363	7,514,149	5,849,617	6,218,131	6,900,350	8,194,699	7,504,064	7,553,959

Other elements, although of secondary importance to N, P, and K, are essential to plant growth and must be supplied to soils deficient in them. Calcium, magnesium, and sulfur are representative of these elements.

Zinc, copper, manganese, iron, and boron are termed minor plant-food elements since they are utilized in small amounts in the growth processes. These elements, in the form of salts, are usually supplied to soils in which they are deficient, at the rate of a few pounds per acre.

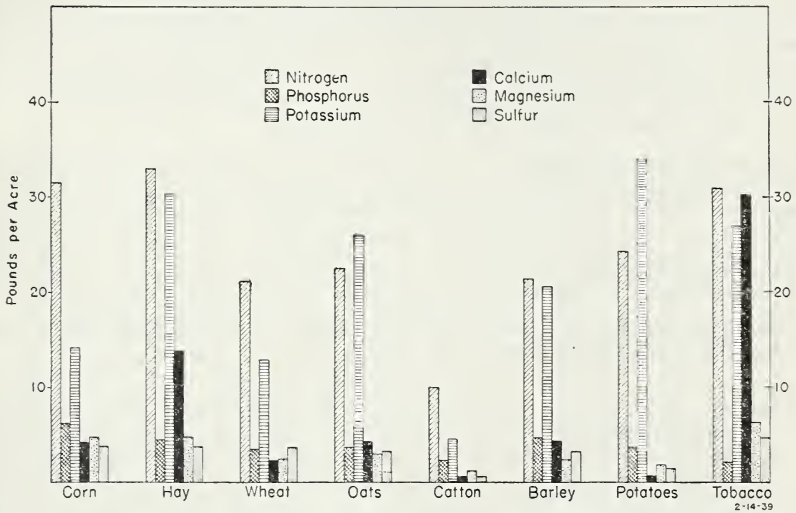

FIGURE 1.—Plant-food elements removed from the soil by various crops.

Figure 1 gives the average quantities of plant-food elements removed by some of the principal crops grown in the United States. These quantities are based on the average yield of the crop for the 10-year period 1927–36.

FOREIGN TRADE IN FERTILIZERS AND FERTILIZER MATERIALS

Foreign trade in fertilizers and fertilizer materials is of considerable importance to the United States and its agriculture. In 1938 the total exports were 1,756,806 tons with a value of $16,531,184, which exceeded the tonnage exported in 1937 by 3 percent although the value was 2½ percent less. In 1938 the imports totaled 1,739,967 tons, valued at $36,496,039. This was 24 percent less in volume and 22 percent less in value than the imports in 1937.

Since it costs as much to ship a ton of fertilizer 200 miles by rail as it does to ship it several thousand miles by steamship and since there are no import duties on fertilizer materials coming into the country, it is possible for European potash to compete in the United States with potash produced, for instance, at Carlsbad, N. Mex. The Atlantic coast is also favorably located for the importation of nitrate of soda, ammonium sulfate, and other fertilizer materials, while the Pacific coast is favorably located for the exportation to the Orient of

fertilizer products now produced in the West in excess of the local demands. Since fertilizers are relatively bulky in comparison with their value, the cost of transportation is a very important item and often limits their use.

NITROGEN

Sources of nitrogen for agricultural crops are considerably different from sources of phosphoric acid and potash. Nitrogen for plant growth is furnished by the addition of fertilizers to the soil, by rain and snow, and by biochemical nitrogen fixation through micro-organisms either living free in the soil or in the nodules of leguminous plants. Roughly two-thirds of the nitrogen utilized by crops is obtained by biochemical fixation.

The commercial sources, exports, and consumption of nitrogen in the United States during 1937 were as follows:

	Tons
Inorganic byproduct nitrogen	150, 000
Synthetic nitrogen	195, 000
Organic nitrogen	60, 000
Imports	182, 000
Exports	37, 000
Consumed in fertilizers	437, 000
Consumed in other industries	130, 000

The nitrogenous materials entering foreign trade in 1938 are given in the following tabulation.

	Tons of nitrogen
Imports:	
Sodium nitrate [1]	92, 000
Ammonium sulfate	25, 000
Cyanamid	26, 000
Cal-Nitro	12, 000
Crude potassium nitrate	7, 000
Calcium nitrate	4, 000
Other fertilizer	14, 000
Industrial chemicals	2, 000
Total	182, 000
Exports:	
Sodium nitrate	25, 000
Ammonium sulfate	6, 000
Ammonium phosphate	3, 000
Other materials for use as fertilizers	1, 000
Industrial chemicals	2, 000
Total	37, 000

[1] Sodium nitrate was imported primarily from Chile. The entire Chilean production for 1935 was 211,584 tons.

Byproduct Inorganic Nitrogen

Byproduct inorganic nitrogen is obtained in the form of ammonia in the coking of coal for the steel industry. The annual production of byproduct ammonia or nitrogen therefore depends largely on the extent of the operation of blast furnaces for the production of pig iron. On the average, about 1 ton of nitrogen may be recovered in the form of ammonia in the production of 300 tons of coke. A maximum production of 188,000 tons of byproduct nitrogen was obtained in 1929 from about 100 coke works in 21 States and a large number of gas works and bone-charring factories. Had the 188,000 tons of

nitrogen all been converted into ammonium sulfate, 900,000 tons of the latter would have resulted. The conversion process consists of bubbling the gases that contain the ammonia through sulfuric acid. The ammonia combines with the sulfuric acid to form ammonium sulfate, which gradually accumulates in the sulfuric acid solution until crystals form. These ammonium sulfate crystals are then separated from the liquor by means of centrifugal machines, washed, and dried. Ammonium sulfate contains 20.6 to 21 percent of water-soluble nitrogen.

Commercial Atmospheric Fixed Nitrogen

The supply of nitrogen in the air is inexhaustible. There are about 35,000 tons over every acre of the earth's surface. Figure 2, which shows the phenomenal world growth of the synthetic nitrogen indus-

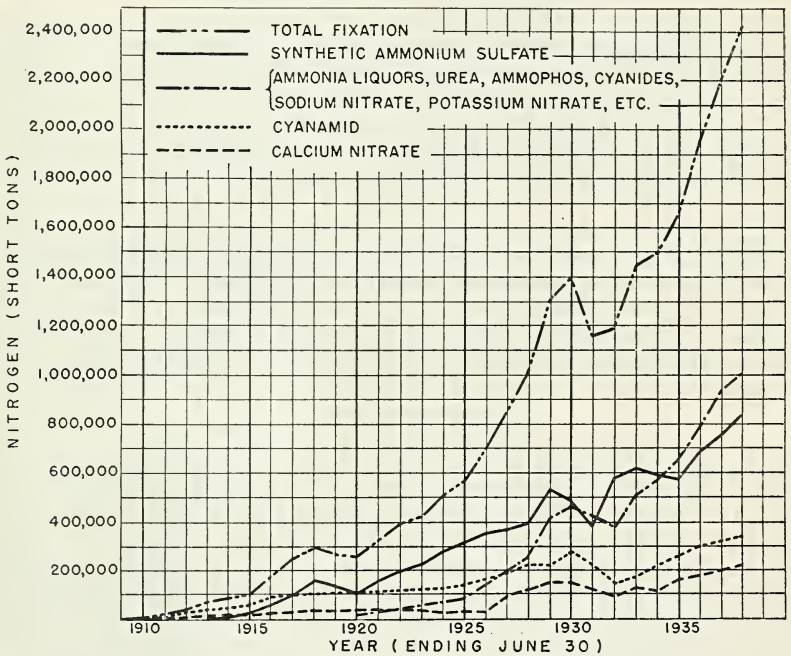

Figure 2.—World production of fixed nitrogen in the form of various materials from 1910 to 1938.

try, indicates a maximum world production of 2,420,000 tons in 1938, with a total capacity estimated at about twice this amount.

In the direct synthetic ammonia process 1 part of nitrogen and 3 parts of hydrogen are combined directly by means of a catalyst to form ammonia. The temperature ranges from 750° to 1,300° F., and the pressure ranges from 100 to 1,000 times atmospheric pressure, depending on the process employed. The hydrogen is obtained either by treating coke with steam, by the electrolysis of water, or as by-product hydrogen from fermentation. A list of the synthetic-nitrogen plants operating in the United States in 1937 and their estimated capacity for that year is given in table 3.

TABLE 3.—*Synthetic-nitrogen plants operating in the United States in 1937 and their capacity for that year*

Company	Location of plant	Nitrogen capacity
		Tons
Mathieson Alkali Works (Inc.)	Niagara Falls, N. Y.	4,800
E. I. du Pont de Nemours & Co. (Inc.), Ammonia Department	Belle, W. Va.	100,000
E. I. du Pont de Nemours & Co. (Inc.), R. & H. Chemicals Dept.	Niagara Falls, N. Y.	3,000
Great Western Electro-chemical Co	Pittsburg, Calif.	750
The Solvay Process Co., Nitrogen Division	Hopewell, Va.	200,000
Dow Chemical Co	Midland, Mich.	4,090
Shell Chemical Co	Pittsburg, Calif.	24,000
Pennsylvania Salt Manufacturing Co	Wyandotte, Mich.	4,800
Total		341,350

Synthetic Sodium Nitrate

One company in the United States, The Solvay Process Co., Hopewell, Va., is producing synthetic nitrate of soda. In this process synthetic ammonia is converted to oxides of nitrogen by passing the ammonia over a catalyst at about 1,380° F. The oxides of nitrogen absorbed in water are neutralized by soda ash (sodium carbonate) and evaporated to dryness, giving sodium nitrate, a white salt, containing 16.2 percent of nitrogen and readily soluble in water. Sodium nitrate is also produced by the reaction of the nitrogen oxides with sodium chloride. The same company makes two liquors, known in the trade as crude nitrogen solution, or Nitrogen Solution I, consisting of sodium nitrate dissolved in ammonia liquor, and Nitrogen Solution II, consisting of ammonium nitrate, ammonia, and water. The nitrogen content of these liquors is about 44 and 37.5 percent, respectively. They are shipped in tank cars and used directly in the manufacture of fertilizers.

Synthetic Urea

One plant in the United States, the E. I. du Pont de Nemours & Co. (Inc.), Ammonia Department, Belle, W. Va., is producing urea. Liquid ammonia and liquid carbon dioxide are brought together in a reaction chamber at about 350° F. and at pressures above 100 atmospheres, forming a liquor containing urea, ammonia, and ammonium carbamate. This liquor in two grades, containing 15 and 20 percent urea nitrogen, is now being shipped in tank cars and used directly in the manufacture of fertilizer. Both grades contain about 45.5 percent of total nitrogen. Crystalline urea is also obtained from this liquor by a relatively simple process, giving another fertilizer material containing 46 percent of nitrogen.

Uramon, containing 42 percent of nitrogen in the form of urea, is now available in considerable tonnage as a fertilizer.

Ureor, recently imported from Europe in small amounts for fertilizer, is a commercial form of urea containing 40 percent of nitrogen. Calsi-Ureor, a similar imported commercial form of urea, contains 30 percent of nitrogen and a magnesium-containing limestone.

Cyanamid

Cyanamid is not manufactured in this country. However, 133,414 short tons were imported in 1938, manufactured at the plant of the American Cyanamid Co., Niagara Falls, Canada. The three prin-

cipal steps in its manufacture are (1) producing calcium carbide by burning limestone to lime and fusing the lime with coke in an electric furnace; (2) separating nitrogen from the air in a fairly pure state; and (3) treating the finely powdered, highly heated carbide with the nitrogen, resulting in the fixation of nitrogen as Cyanamid, a product containing 22.3 percent of nitrogen.

Cal-Nitro is a mixture of calcium carbonate and ammonium nitrate. The calcium carbonate may be either a byproduct or ground limestone. This material was first produced in Germany, but it is now manufactured in other countries in Europe by modifications of the German process. Two grades, containing 16 and 20.5 percent of nitrogen, respectively, are now available. Calcium nitrate is produced by treating limestone with nitric acid. It contains 16.1 percent of nitrogen.

Organic Nitrogen Carriers

The organic ammoniates are of vegetable or animal origin, and some carry small amounts of phosphoric acid and potash in addition to the nitrogen. The increasing demand for some of these materials for cattle feed is decreasing the amount going into fertilizers. However, a rather large quantity is still consumed as fertilizers. The following tabulation shows the organic materials used as fertilizers in 1937.

	Tons
Cottonseed meal	125, 000
Process tankage	118, 000
Animal tankage and dried blood	45, 000
Garbage tankage	63, 000
Fish scrap	79, 000
Guano	71, 000
Bones	85, 000
Sewage sludge	92, 000
Tobacco stems	90, 000
Other organic ammoniates	96, 000
Total	864, 000

Waste Organic Materials

Sewage sludge and garbage are the two principal sources of waste organic materials practically unused at present but of potential commercial fertilizer value. Numerous attempts have been made to use these as fertilizer material, but none has been entirely successful economically. It is estimated that there is an annual loss of more than 417,000 tons of nitrogen, 120,000 tons of phosphoric acid, and 92,000 tons of potash in the unused sewage and garbage of the larger urban communities. The nitrogen wasted is comparable in quantity to that consumed in commercial fertilizers. At the present prices of inorganic fertilizers, the three plant-food elements lost have a wholesale value of $65,000,000 annually.

Wholesale Cost of Fertilizer Nitrogen

The phenomenal growth of the synthetic nitrogen-fixation industry since the World War has very greatly affected the relative quantities of the nitrogenous materials used as fertilizers and their relative prices. By the synthetic method it is possible to produce an almost

unlimited supply of fixed nitrogen for agriculture, as well as for nitrates for explosives for public defense.

The establishment of nitrogen-fixation plants is beyond a doubt motivated by the thought of national independence in this basic necessity in times of war. The increasing production of synthetic ammonia and synthetic sodium nitrate in this country since about 1923 has been a major factor in the present low cost of fertilizer nitrogen. Figure 3 lists the average wholesale price of nitrogen in various mate-

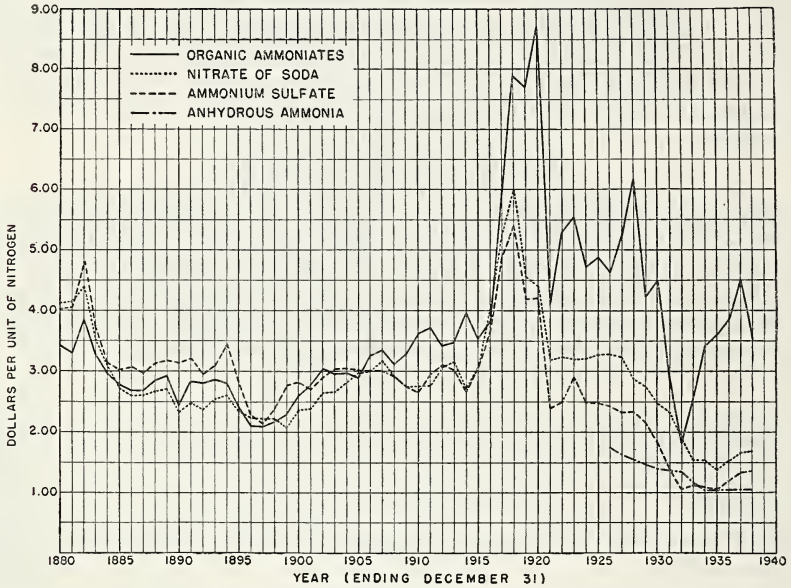

FIGURE 3.—Annual average wholesale spot price per unit of nitrogen in various materials at producing points or ports in bulk from 1880 to 1938.

rials used in fertilizers from 1880 to 1938, inclusive. Fertilizer nitrogen is now available at a wholesale price as low as 5½ cents a pound. The growing demand for organic ammoniates such as cottonseed meal, fish scrap, animal tankage, and dried blood for cattle feed has increased the wholesale price of the nitrogen in the organic ammoniates from two to four times the cost of nitrogen in anhydrous ammonia and ammonium sulfate.

PHOSPHATES

Phosphate Rock

Phosphate fertilizers are produced largely by chemically treating phosphate rock. The United States is especially fortunate in that it has the most extensive deposits of phosphate rock discovered to date. The supply is estimated at approximately 8.1 billion tons, out of a total world supply conservatively estimated at 19.3 billion tons. At the present rate of consumption the United States deposits will supply the entire domestic requirements for phosphates for approximately 2,000 years. At the present rate of production the deposits now being worked, largely those of Florida and Tennessee, should

supply the country's needs for 200 years. The extensive deposits of Idaho, Montana, Utah, and Wyoming, which are not appreciably developed, constitute a reserve for centuries to come.

The world production of phosphate rock amounted to approximately 13,193,000 short tons in 1937, of which the United States produced 3,754,000 tons, or 28 percent. In 1937, 95,349 tons of mineral phosphate in the form of very fine pond settlings and as finely ground phosphate rock were applied directly to the soil as fertilizer. In general, finely divided, raw material phosphate, which usually contains about 2 percent and almost always less than 5 percent of available P_2O_5, as determined by the official ammonium citrate method, is not utilized as readily by plants as is the chemically processed material.

Superphosphate

The leading phosphate fertilizer in both quantity and value in the United States and in the world is superphosphate. In 1937 production of superphosphate reached the world peak of 18,535,000 tons. About 90 percent of the phosphate fertilizer consumed in the United States

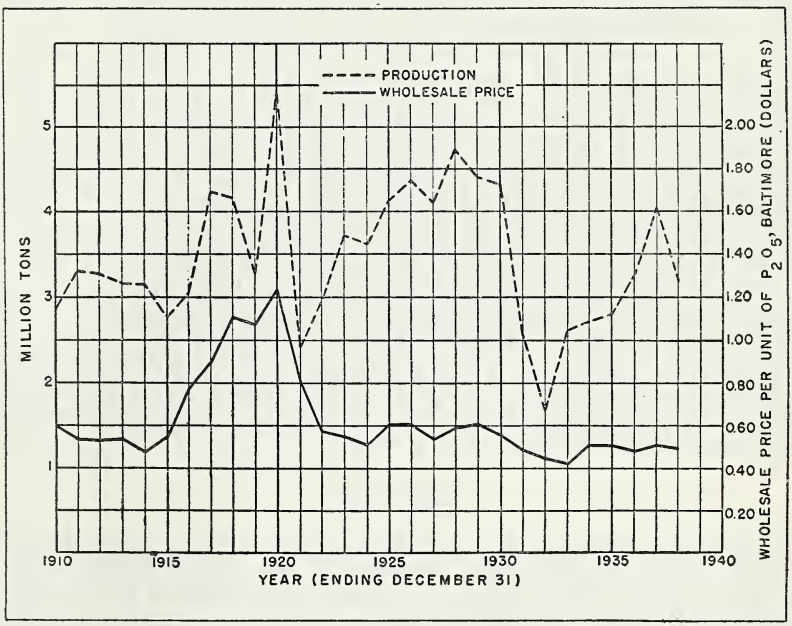

FIGURE 4.—Annual production and average wholesale price of superphosphate from 1910 to 1938.

in 1937 was used in this form. Superphosphate is made by mixing 1 part, by weight, of finely ground phosphate rock with a quantity of sulfuric acid equivalent to about 1 part of 50° Baumé acid. The sulfuric acid converts the insoluble phosphoric acid of the rock into forms that can be readily utilized by plants. The mixture of phosphate rock and sulfuric acid is vigorously stirred for a few minutes and then discharged into a den, where it soon solidifies. It is usually allowed to remain here for several hours. The product is then trans-

ferred to the storage pile, where it is usually left for several weeks to improve the physical condition of the material and increase the availability of the phosphoric acid. The content of available P_2O_5 in the product ordinarily ranges from 16 to 20 percent, depending on the grade of rock used. As superphosphate contains about 50 percent of calcium sulfate, it is a valuable source of sulfur for soils deficient in this element.

The trend in production and price of superphosphate is shown in figure 4. The production figures show the total actual tonnage of all superphosphates produced, including double superphosphate, wet mixed base, and limed superphosphate. The prices are for run-of-pile material in bulk f. o. b., Baltimore, Md. Run-of-pile implies that the purchaser accepts the P_2O_5 content of the pile whatever it may be. It ranges from 16 to 20 percent, depending on the rock and variations in processing.

Double or Triple Superphosphate

Double or triple superphosphate, which usually contains 42 to 50 percent of available P_2O_5, is made by treating finely ground phosphate rock with liquid phosphoric acid. The phosphoric acid so used is produced by treating phosphate rock with sulfuric acid or by smelting a mixture of phosphate rock, silica, and coke in an electric or blast furnace. In 1937 about 125,000 tons of double superphosphate were produced and sold in the United States. In addition, during the year ending June 30, 1937, the Tennessee Valley Authority distributed 34,000 tons of triple superphosphate to farmers for experimental demonstrations, largely within the Tennessee Valley. The phosphoric acid used by the Tennessee Valley Authority in manufacturing triple superphosphate at Muscle Shoals is made by the electric furnace process, whereas the phosphoric acid used by the fertilizer industry in manufacturing triple superphosphate is made principally by the sulfuric acid process, although some is made by the electric and blast-furnace processes. The total production of triple superphosphate by the Tennessee Valley Authority to July 1, 1938, was 127,659 tons. In 1937 the imports of superphosphate containing more than 20 percent of P_2O_5 totaled 14,733 tons.

Basic Slag

Thirty-six thousand tons of open-hearth basic slag containing about 9 percent of P_2O_5 were produced in the United States in 1936. In the same year 1,000 tons of basic slag containing 15 to 16 percent of P_2O_5 were imported from Europe.

Bonemeal

In 1937 about 85,000 tons of bonemeal containing 22 percent of P_2O_5 were consumed in the United States.

Proposed New Phosphate Fertilizers

During the fiscal year 1938 the Tennessee Valley Authority produced on a pilot-plant scale, 4,246 tons of calcium metaphosphate, a new phosphate fertilizer material containing from 60 to 65 percent

of available P_2O_5. Calcium metaphosphate is prepared by burning phosphorus with air and bringing the hot phosphorus pentoxide vapor in contact with phosphate rock. The molten calcium metaphosphate, which is tapped from the bottom of the furnace at frequent intervals, solidifies to a glassy mass that can be easily crushed to the desired fineness.

The Fertilizer Research Division of the Bureau of Agricultural Chemistry and Engineering has done considerable work on a product known as calcined or defluorinated phosphate rock. When phosphate rock is heated in the presence of water vapor at about 2,550° F. for a short time, the fluorine is volatilized, and a product containing 30 to 35 percent of available P_2O_5 is obtained. The sintered or semifused clinkers need only to be ground for use as a fertilizer. Although this material has been made successfully in rotary kilns on a pilot-plant scale, attempts to produce it on a commercial scale have not given satisfactory results.

An experimental furnace for the fusion and the defluorination of phosphate rock, giving a product containing about 30 percent of available P_2O_5, is being developed by the Tennessee Valley Authority.

Phosphates as Carriers of Nitrogen

One of the most significant advances in fertilizer manufacture during the past 10 years was the general adoption of a practice of utilizing superphosphate and double superphosphate to absorb free ammonia. Either anhydrous or aqua ammonia is admitted to a closed rotating drum containing either superphosphate or double superphosphate. The heat generated by the reaction, together with the rotation of the drum, produces a very desirable granular product possessing excellent physical characteristics. About 3 percent of ammonia can easily be added to superphosphate and up to 6 percent of ammonia to double superphosphate without loss of available plant food. There is an increasing demand for these ammoniated products. Most of the superphosphate used in making mixed fertilizers in large plants is now ammoniated in the course of the preparation of the fertilizer mixtures.

In 1937 about 65,000 tons of ammonium phosphate were consumed as fertilizers in the United States.

POTASH

The potash industry in the United States produces potash from minerals mined near Carlsbad, N. Mex., from the brine of Searles Lake at Trona, Calif., and of Salduro Marsh, Wendover, Utah, as a byproduct of the cement industry at Security, Md., and as a byproduct of the alcohol industry at Baltimore, Md.

The potash minerals that have been identified in drill cores from Texas and New Mexico include polyhalite (hydrous potassium-calcium-magnesium sulfate), sylvite (potassium chloride), carnallite (hydrous potassium-magnesium chloride), kainit (hydrous potassium-magnesium chloride-sulfate), langbeinite (potassium-magnesium sulfate), and leonite (hydrous potassium-magnesium sulfate). Polyhalite is the most abundant potash mineral, followed by sylvite. Production of potash from sylvite deposits was begun by one company in 1931 and by a second in 1934. In the same locality a third com-

pany has recently completed a shaft that cuts beds containing important quantities of langbeinite mixed with sylvite. The proved area of commercial potash salts in New Mexico covers 33 square miles and comprises a reserve of more than 100,000,000 tons of soluble potash salts averaging 26 to 28 percent of actual potash. Sylvite, carnallite, and langbeinite have been found in an area covering 3,000 square miles.

The brine of Searles Lake contains chlorides, sulfates, carbonates, and tetraborates of potassium and sodium, and small amounts of other salts. It contains about 1.3 percent of sodium tetraborate and 2.5 percent of potash. The actual potash content has been estimated as 20,000,000 tons. This brine has been used for the manufacture of potash since about 1911. The production of potash by solar evaporation was resumed in 1938, from the brine of Salduro Marsh, for the first time since the close of the World War. Other salt lakes in Nebraska, Utah, Nevada, and California contain appreciable quantities of potash, but no reliable estimates of their total potash content are available.

It is believed that the giant kelps of the Pacific coast are capable of supplying potash as a byproduct in the manufacture of decolorizing carbons, iodine, ammonia, acetone, or algin. At present no potash is derived directly from this source.

It is estimated that industrial wastes from the blast furnace, cement, alcohol, and sugar industries are capable of supplying from 500,000 to 600,000 tons of potash annually. In 1938 the cement and alcohol industries marketed some potash.

In addition the United States possesses almost inexhaustible reserves of water-insoluble potash minerals. Large deposits of alunite ($K_2O.3Al_2O_3.6H_2O$) containing from 9.0 to 11.4 percent of potash are found in Utah, Colorado, and Nevada. It is estimated that the Leucite Hills of Sweetwater County, Wyo., contain 200,000,000 tons of potash in silicate combination. The greensands of New Jersey are believed to contain more than 257,000,000 tons of potash as glauconite (hydrous potassium-iron silicate). Large deposits of greensands occur also in Delaware, Maryland, Texas, and Virginia. Many million tons of hydrous potassium silicates containing from 7 to 9 percent of potash occur near Cartersville, Ga. Orthoclase feldspar, which is widely distributed throughout the United States, also contains potash. The cost of production of potash salts from these water-insoluble minerals is too high at present, however, to permit competition with either the domestic or the foreign water-soluble sources.

The present capacity for potash production is estimated as more than 400,000 tons of potash annually. With the exception of the mines in New Mexico, the domestic production of potash is limited to some extent by the market for the products obtained simultaneously with potash either as a coproduct or as a byproduct. The production for 1938 was approximately 317,000 tons, as is shown in figure 5. This chart gives the domestic production, imports, and wholesale price of potash in the form of the muriate from 1910 to 1938. The magnitude and value of the potash materials imported into the United States in 1937 and 1938 are indicated in table 4.

TABLE 4.—*Potash materials imported into the United States in 1937 and 1938*

Material	Approximate potash (K_2O) content	1937				1938			
		Total quantity	Approximate potash (K_2O) content		Wholesale value	Total quantity	Approximate potash (K_2O) content		Wholesale value
	Percent	*Tons*	*Tons*	*Percent*	*Dollars*	*Tons*	*Tons*	*Percent*	*Dollars*
Kainit	14.0	974	136		7,238	402	56		2,528
Do	20.0	129,051	25,810	7.3	1,131,898	59,811	11,962	6.2	523,229
Manure salts	31.4	44,909	14,101	4.0	591,804	9,169	2,879	1.5	112,713
Muriate (chloride)	56.4	417,682	235,573	67.0	9,725,200	223,542	126,078	65.1	5,371,600
Nitrate of soda-potash	14.0	61,271	8,578	2.4	1,309,386	44,493	6,229	3.2	971,646
Nitrate (crude)	40.0	17,272	6,909	2.0	761,764	14,648	5,859	3.0	680,602
Potash-magnesia sulfate	27.0	22,375	6,041	1.7	453,026	13,158	3,553	1.8	281,691
Sulfate	50.0	93,694	46,847	13.3	2,851,880	59,855	29,928	15.5	1,910,819
Other potash fertilizer material [1]	60.0	255	153		1,952	184	110	.1	1,373
Total		787,483	344,148	97.7	16,834,148	425,262	186,654	96.4	9,856,201

[1] Chiefly wood ashes from Canada.

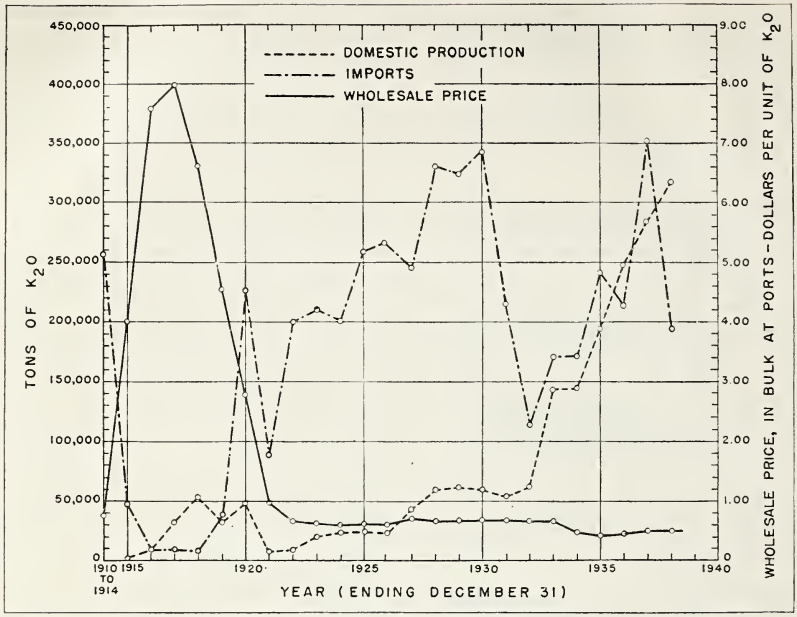

FIGURE 5.—Domestic production, imports, and wholesale price of potash from 1910 to 1938.

MURIATE OF POTASH

Muriate of potash, or commercial potassium chloride, is manufactured in the United States in grades containing from 50 to 63 percent of potash. It is by far the major source of agricultural potash. The American Potash and Chemical Corporation produces muriate by evaporation and fractional crystallization of Searles Lake brine. Borax, boric acid, salt cake, soda ash, and lithium salts are produced as coproducts with the muriate. Bonneville, Ltd., produces the muriate at Wendover, Utah, by solar evaporation of the brine of Salduro Marsh.

Both the United States Potash Co. and the Potash Co. of America produce muriate at Carlsbad, N. Mex., from sylvite-halite ore but by totally different methods. The process employed by the United States Potash Co. is based on the greater solubility of potassium chloride in hot saturated salt solutions than in cold and the fact that the solubility of sodium chloride varies only slightly with temperature changes. The Potash Co. of America employs ore-dressing methods for the separation of sylvite and halite. The ore is ground, and the sylvite is selectively floated in a saturated brine solution with the use of a frothing reagent.

MANURE SALTS

Manure salts are primarily mechanical mixtures of sodium and potassium chlorides. The sodium chloride predominates. The usual grades contain 25 to 30 percent of potash. They are produced by

mixing run-of-mine material with muriate or with waste sodium chloride residues from the preparation of the muriate, depending on the composition of the run-of-mine material and the grade of manure salts to be produced.

Kainit

The mineral kainite, a hydrous potassium-magnesium chloride-sulfate, is usually found associated with sodium and potassium chlorides. The mixture, known as kainit, is not produced in this country but as mined in Germany contains from 10 to 12 percent of potash. Originally this run-of-mine material was marketed as such. More recently it has been enriched with muriate and sold primarily as 20 percent kainit. However, since it is not necessary to guarantee the kainit or magnesium content, various mixtures that may or may not contain kainit are marketed as kainit. For example, 20 percent manure salts are now marketed as 20 percent kainit.

Sulfate of Potash-Magnesia

Sulfate of potash-magnesia, a double sulfate of potassium and magnesium, contains from 48 to 53 percent of potassium sulfate, equivalent to 26 to 28 percent of potash, and 25 to 35 percent of magnesium sulfate. The double sulfate separates as fine crystals when kainite is dissolved in water or when solutions of langbeinite or kieserite (hydrous magnesium sulfate) are mixed with solutions of potassium chloride. The double sulfate is recovered by filtration and dried. Although sulfate of potash-magnesia has never been produced in this country, the mixtures of langbeinite and sylvite cut by the shaft of the Union Potash and Chemical Corporation near Carlsbad, N. Mex., are potential sources of both the double sulfate and potassium sulfate.

Potassium Sulfate

Potassium sulfate is precipitated when concentrated solutions of potassium chloride and of the double sulfate of potassium and magnesium are mixed. The potassium sulfate is separated by filtration and dried. No domestic production by this process has been reported. A small tonnage of potassium sulfate, however, is being produced from potassium chloride and sulfuric acid in the production of hydrochloric acid for use in working oil wells. The North American Cement Corporation, Security, Md., by fractional precipitation of cement-kiln dust recovers a product that contains about 22 percent of potash, combined chiefly as the sulfate.

Vegetable Potash

The United States Industrial Chemical Co., Baltimore, Md., incinerates evaporated distillery waste produced in the manufacture of cane molasses and markets the char in two grades, containing 33.5 and 55 percent of potash, under the trade name Vegetable Potash. The 55-percent grade is essentially a mixture of the sulfate and chloride.

Potassium Nitrate

No potassium nitrate is produced in this country for agricultural purposes. The bulk of the material reaching the market is Chilean saltpeter or Nitrapo, an imported mixture of sodium and potassium nitrates containing about 14 percent of potash, as compared with 46.6 percent for pure potassium nitrate. A smaller quantity of crude, approximately 95-percent potassium nitrate or Potnit is imported, chiefly from Europe.

Potassium Metaphosphate

Preliminary vegetative tests have shown that potassium metaphosphate is an excellent source of both potash and phosphoric acid. It is nonhygroscopic, nearly water insoluble, and on the basis of its composition, 40 percent of potash and 60 percent of phosphoric oxide, it is a 100-percent plant food. Methods for its production from potassium chloride and phosphoric acid or oxide are being studied by the Department.

Tobacco Stems

In 1937, 90,000 tons of tobacco stems, containing about 5 percent of K_2O, were consumed as fertilizer.

FERTILIZER PLANTS AND MANUFACTURERS

The United States Census Bureau reported 638 fertilizer establishments in 1929, 522 in 1933, 670 in 1935, and 743 in 1937. These are engaged primarily in the production of commercial fertilizer (mixed fertilizers and superphosphates). They do not include the firms engaged in the production of fertilizer materials other than superphosphate or about 300 plants with an annual production valued at less than $5,000, since these account for a negligible portion of the national output. About three-fourths of the plants are dry-mixing plants, that is, they take in finished raw materials and prepare mixed fertilizers. About 200 plants produce superphosphate, and half of these have their own sulfuric acid plants.

Figure 6 indicates the location of the larger plants that either process the materials or fabricate mixed fertilizers and superphosphates.[3]

The American Fertilizer Hand Book and the Yearbook of Commercial Fertilizer, which are available in the larger libraries and at most State experiment stations, give lists of fertilizer manufacturers and locations of plants as well as information about the production and consumption of fertilizers.

[3] From data given in The Fertilizer Review v. 13, p. 8. 1938.

FIGURE 6.—Location of fertilizer plants of the United States.

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